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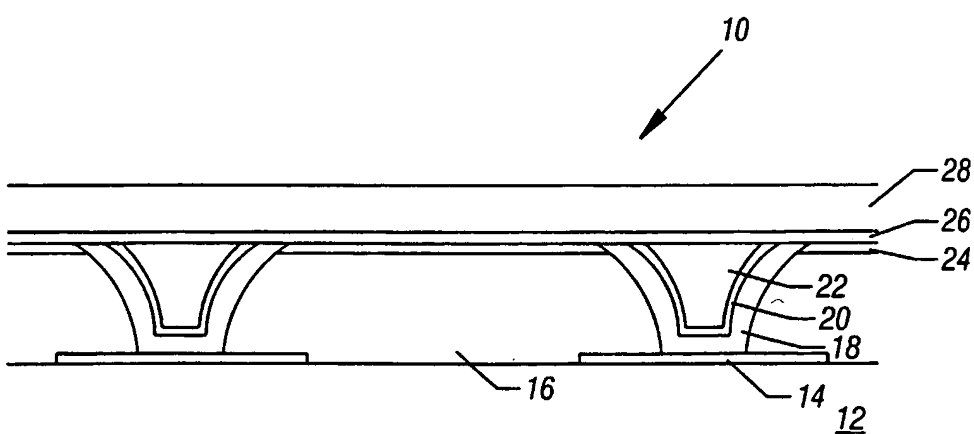
(54) Title: PHASE CHANGE MATERIAL MEMORY DEVICE



(57) Abstract: A phase change material memory cell (10) may be formed with singulated, cup-shaped phase change material (18). The interior of the cup-shaped phase change material (18) may be filled with a thermal insulating material (22). As a result, heat losses upwardly through the phase change material (18) may be reduced and adhesion problems between the phase change material (18) and the rest of the device (10) may likewise be reduced in some embodiments. In addition, a barrier layer (20) may be provided between the upper electrode (28) and the remainder of the device (10) that may reduce species incorporation from the top electrode (28) into the phase change material (18), in some embodiments. Chemical mechanical planarization may be utilized to define the phase change material (18) reducing the effects of phase change material dry etching in some embodiments.

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Phase Change Material Memory Device

Background

This invention relates generally to electronic memories and particularly to electronic memories that use phase change material.

Phase change materials may exhibit at least two different states. The states may be called the amorphous and crystalline states. Transitions between these states may be selectively initiated. The states may be distinguished because the amorphous state generally exhibits higher resistivity than the crystalline state. The amorphous state involves a more disordered atomic structure. Generally any phase change material may be utilized. In some embodiments, however, thin-film chalcogenide alloy materials may be particularly suitable.

The phase change may be induced reversibly. Therefore, the memory may change from the amorphous to the crystalline state and may revert back to the amorphous state thereafter, or vice versa, in response to temperature changes. In effect, each memory cell may be thought of as a programmable resistor, which reversibly changes between higher and lower resistance states. The phase change may be induced by resistive heating.

In some embodiments, the cell may have a large number of states. That is, because each state may be distinguished by its resistance, a number of resistance determined states may be possible, allowing the storage of multiple bits of data in a single cell.

A variety of phase change alloys are known. Generally, chalcogenide alloys contain one or more elements from Column VI of the periodic table. One particularly suitable group of alloys is the GeSbTe alloys.

A phase change material may be formed within a passage or pore through an insulator. The phase change material may be coupled to upper and lower electrodes on either end of the pore.

One problem that arises is that the adherence between the insulator and the phase change material may be poor. One solution to this problem is to provide an interfacial layer that promotes adhesion between the insulator and the phase change material. Generally, suitable interfacial layers are conductors such as titanium.

In particular, because of the use of extended lengths of phase change material, the possibility of separation arises. The use of column stripes of phase change material may require adhesion along long stripes despite the thermal expansion and contraction from subsequent processing steps. There is also accumulative stress along the column line from

the phase change material stack itself and from subsequent thin-film depositions required as part of integration into an integrated circuit process flow.

Alternatively, a glue layer may be positioned between the insulator and the phase change material. However, the glue layer may degrade the phase change material or add processing cost.

Another issue with existing phase change memories is upwardly directed heat loss through the cell. The more the heat loss, the greater the programming current that is required since heat is utilized to induce the programming phase change.

Still another problem is the incorporation of species from the upper electrode into the phase change material. Species incorporation can have detrimental effects on programming properties of the phase change material.

Yet another issue with existing phase change material memories is the need for dry etching of the phase change material. The dry etch of a phase change material stack is a complicated process. Issues of undercut and re-entrant profiles may be encountered.

Thus, there is a need for better designs for phase change memories that may be manufactured using more advantageous techniques.

Brief Description of the Drawings

Figure 1 is an enlarged, cross-sectional view in accordance with one embodiment of the present invention;

Figure 2 is an enlarged, cross-sectional view of the device shown in Figure 1 taken transversely to the view shown in Figure 1;

Figure 3 is a top plan view of the embodiment shown in Figures 1 and 2;

Figure 4 is an enlarged cross-sectional view of the initial processing of the structure of Figure 1 in accordance with one embodiment of the present invention;

Figure 5 shows subsequent processing on the structure shown in Figure 4 in accordance with one embodiment of the present invention;

Figure 6 shows subsequent processing of the structure shown in Figure 5 in accordance with one embodiment of the present invention; and

Figure 7 shows subsequent processing of the embodiment shown in Figure 6 in accordance with one embodiment of the present invention.

Detailed Description

Referring to Figure 1, a phase change memory cell 10 may be formed on a substrate 12 that in one embodiment may be a silicon substrate. A pair of lower electrodes 14 may be formed over the substrate 12. The electrodes 14 may be separated by an insulator 16. A pore may be formed above the lower electrode 14 between the lower electrode 14 and the top electrode 28. The pore may include a tapered, cup-shaped phase change material 18 covered by a similarly shaped barrier layer 20. A fill insulator 22 may fill the central portion of the barrier 20 and the phase change material 18. An etch stop layer 24 underlies a barrier layer 26 that in turn underlies the top electrode 28.

Referring to Figure 2, the top electrode 28 extends along two adjacent pores. The pores may be separated by an insulator 16. Cells defined by the pores may be distributed in large numbers across the substrate 12 in some embodiments. As viewed from above in Figure 3, each electrode 28 covers a plurality of pores including the elements 14, 18, 20 and 22, separated by insulator 16 covered by an etch stop layer 24.

A technique for forming the memory cells 10, according to one embodiment, may involve initially forming the lower electrodes 14 on a substrate 12 using conventional patterning and deposition techniques, as shown in Figure 4. Any conventional technique may be utilized to form the electrodes 14. The electrodes 14 may be formed of a variety of conductors including cobalt silicide.

The insulator 16 may then be deposited over the patterned lower electrodes 14. In one embodiment, the insulator 16 is an electrical and thermal insulator. One suitable material is silicon dioxide that may be from about 50 to 1500 Angstroms thick in one embodiment. Next a planarization such as, for example, a chemical mechanical planarization (CMP) is performed to achieve global and local planarity. This may be followed by the deposition, if desired, of a CMP etch stop layer 24. The layer 24 may be silicon nitride or polysilicon having a thickness from 10 to 1000 Angstroms in one embodiment.

Referring next to Figure 5, the pore openings 32, defined through the etch stop layer 24, receive a side wall spacer 30. The side wall spacer 30 may be formed using standard techniques of depositing an insulating layer and selectively anisotropically dry etching that layer from the lower electrode 14 and the etch stop layer 24. An insulating spacer 30 may be made of silicon dioxide or nitride such as Si_3N_4. The thickness of the insulating spacer 30 may be in the range of 50 to 2000 Angstroms in one embodiment.

Turning next to Figure 6, deposited in a sequential fashion over the structure shown in Figure 5 may be the phase change layer 18, barrier layer 20, and fill insulator 22, in one embodiment. The phase change material 18 may be a chalcogenide-based material such as $Ge_2Sb_2Te_5$ with a thickness of 50 to 1000 Angstroms in one embodiment. The barrier material 20 may be, for example, titanium, titanium nitride or titanium-tungsten, for example, with a thickness in the range of 10 to 500 Angstroms. The fill insulator 22 may be any insulator with low thermal and electrical conductivity. Examples of suitable fill insulator 22 materials include silicon dioxide or silicon nitride, such a Si_3N_4 with a thickness of about 500 to 10,000 Angstroms, for example.

Turning finally to Figure 7, CMP removes the fill insulator 22, barrier layer 20, and phase change material 18 in all regions above the etch stop layer 24. CMP thereby defines the structure of the phase change material 18 while eliminating the need for a dry etch in one embodiment. As mentioned earlier, the use of the dry etch may complicate the process flow and raise issues of undercut and re-entrant profiles. Moreover, because the phase change material 18 is defined within an encapsulated, singulated region, the problem of adhesion between the phase change material 18 and the surrounding materials may be substantially reduced or even eliminated, even after exposure to ensuing thermal stresses.

The imposition of the insulator 22 over the phase change material 18 reduces upward thermal losses. Thermal losses may result in the need for greater programming currents to obtain the same programming effect.

As shown in Figure 1, the structure of Figure 7 may be covered with a barrier layer 26 and a top electrode 28. In one embodiment, the barrier layer 26 may be titanium, titanium nitride, or titanium-tungsten at a thickness in the range of 10 to 500 Angstroms. The top electrode 28 may be aluminum copper alloy in one embodiment with a thickness in the range of 200 to 20,000 Angstroms. The use of a barrier layer 26 may reduce the incorporation of species from the top electrode 28 into the phase change material 18 in some embodiments. The top electrode 28 and barrier layer 26 may be patterned using standard photolithographic and dry etching techniques to achieve the structures shown in Figure 1, 2, and 3.

While the present invention has been described with respect to a limited number of embodiments, those skilled in the art will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of this present invention.

What is claimed is:

1. A method comprising:
defining a singulated opening;
forming a cup-shaped phase change material in said opening; and
forming a thermally insulating material in the cup-shaped phase change material.

2. The method of claim 1 including forming an electrode and a barrier layer, said electrode coupled to said phase change material through said barrier layer.

3. The method of claim 1 including forming an electrode electrically coupled to said phase change material, and isolating species in said electrode from said phase change material using a barrier layer.

4. The method of claim 1 including insulating said phase change material to reduce upwardly directed heat loss.

5. The method of claim 1 including defining said phase change material using a planarization process.

6. The method of claim 5 including defining said phase change material using a chemical mechanical planarization technique.

7. The method of claim 1 including defining a side wall spacer in said singulated opening.

8. The method of claim 7 including defining an electrode in said opening.

9. The method of claim 8 including using said side wall spacer to define the cup-shape of said phase change material.

10. A memory comprising:

a support structure;

an insulator over said support structure, said insulator having an opening defined in said insulator;

a cup-shaped phase change material in said opening; and

a thermally insulating material in said cup-shaped phase change material.

11. The memory of claim 10 wherein said thermally insulating material fills said cup-shaped phase change material.

12. The memory of claim 10 including an electrode and a barrier layer between said electrode and said phase change material, said electrode coupled to said phase change material through said barrier layer.

13. The memory of claim 10 including an electrode electrically coupled to the phase change material to isolate species in the electrode from the phase change material.

14. The memory of claim 10 including an insulator over the phase change material to reduce upwardly directed heat loss.

15. The memory of claim 10 wherein said phase change material is singulated.

16. The memory of claim 15 including a side wall spacer in said singulated opening.

17. The memory of claim 16 including an electrode in said opening.

18. The memory of claim 17 wherein said cup-shaped phase change material is formed over said side wall spacer.

19. The memory of claim 10 wherein the phase change material is generally parallel to the side wall spacer.

20. A method comprising:

defining a phase change material;

forming an electrode over said phase change material; and

isolating said electrode from said phase change material.

21. The method of claim 20 including incorporating a barrier layer between said phase change material and said electrode.

22. The method of claim 21 including incorporating a barrier layer of a conductor.

23. The method of claim 22 including forming said barrier layer of titanium nitride.

24. A memory comprising:

a phase change material;

an electrode over said phase change material; and

a barrier layer between said phase change material and said electrode.

25. The memory of claim 24 wherein said barrier layer is a conductive layer.

26. The memory of claim 25 wherein said barrier layer includes titanium.

27. The memory of claim 24 wherein said barrier layer prevents species in said electrode from entering said phase change material.

28. A method comprising:

defining an opening in a structure;

forming a layer of phase change material into said opening and over said structure; and

planarizing said phase change material.

29. The method of claim 28 including chemical mechanical planarizing said phase change material.

30. The method of claim 28 including forming a side wall spacer in said opening and then depositing said phase change material.

31. The method of claim 28 including forming a cup-shaped phase change material.

32. The method of claim 31 including filling said cup-shaped phase change material with an insulator.

33. A memory comprising:
a support structure;
an opening in said support structure; and
a planarized phase change material in said opening.

34. The memory of claim 33 wherein said phase change material is cup-shaped.

35. The memory of claim 34 including an insulator in said cup-shaped phase change material.

36. The memory of claim 33 wherein said phase change material is encapsulated.

37. The memory of claim 33 wherein said phase change material is singulated.

38. The memory of claim 33 including an electrode coupled to said phase change material.

39. The memory of claim 38 including a barrier layer between said electrode and said material.

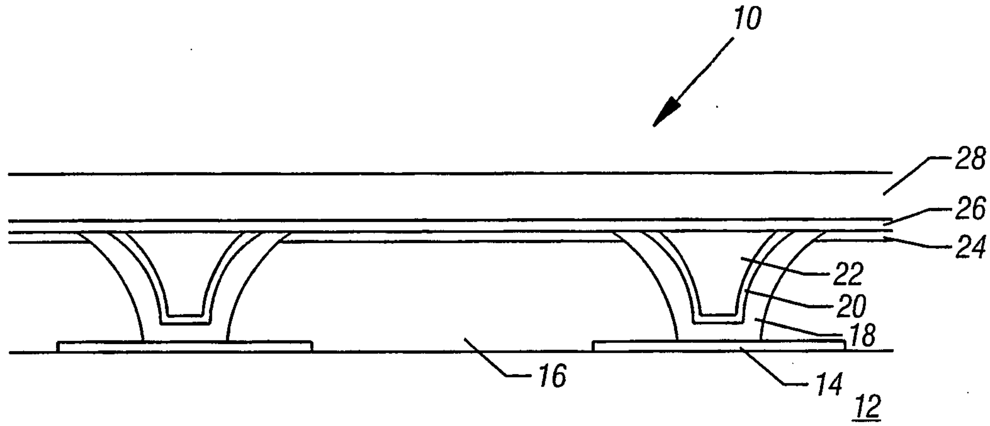

FIG. 1

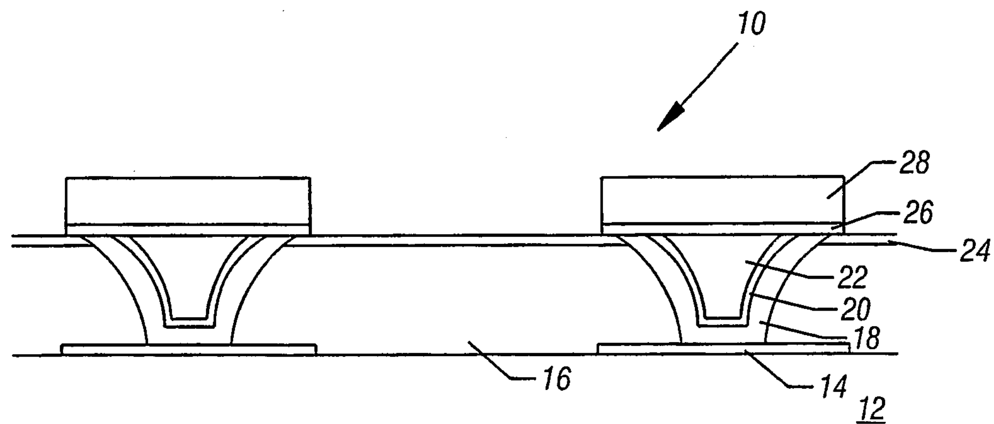

FIG. 2

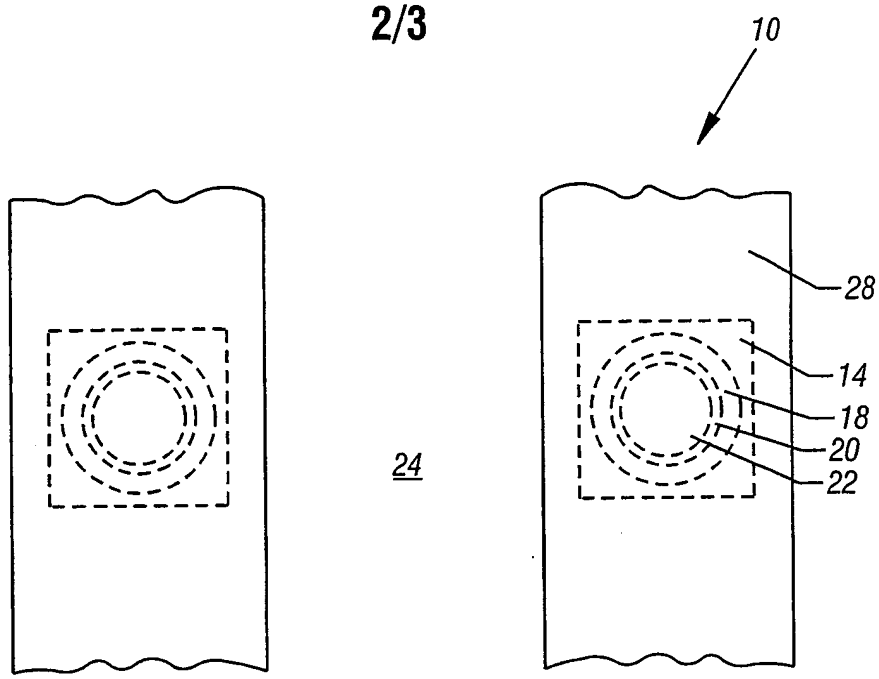

FIG. 3

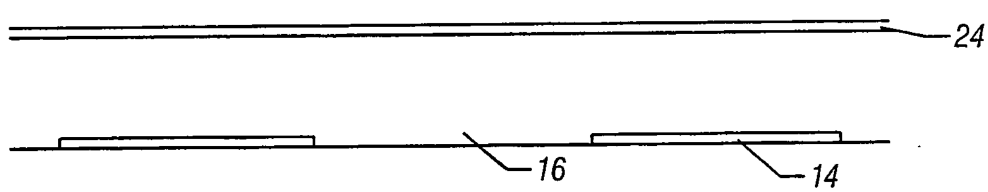

FIG. 4

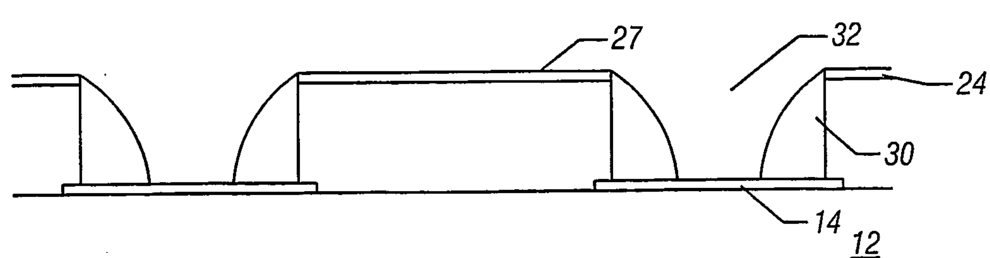

FIG. 5

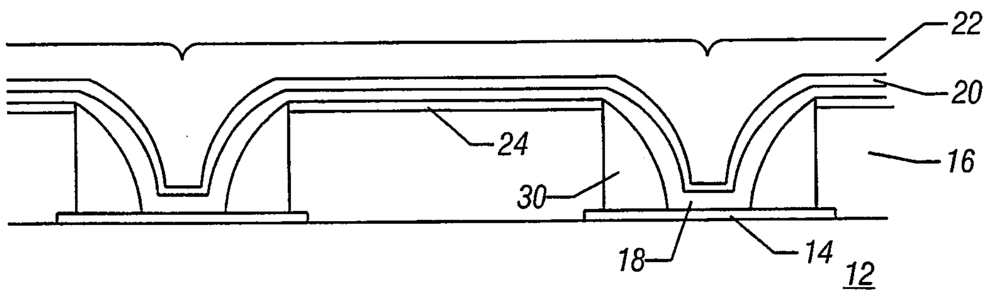

FIG. 6

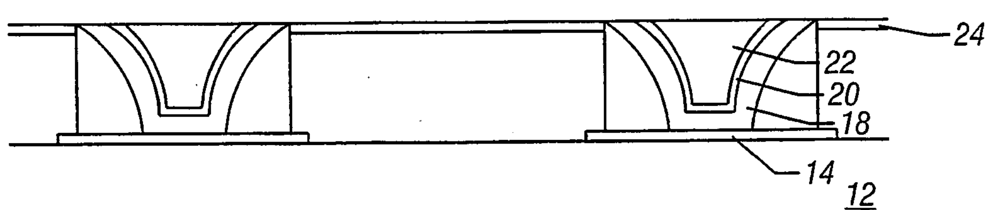

FIG. 7

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(71) Applicant: INTEL CORPORATION [US/US]; 2200 Mission College Blvd., Santa Clara, CA 95054-1549 (US).

(72) Inventor: LOWREY, Tyler, A.; 516 Mill River Lane, San Jose, CA 95134 (US).

(74) Agents: TROP, Timothy, N. et al.; TROP, PRUNER & HU, P.C., 8554 Katy Freeway, Suite 100, Houston, TX 77024 (US).

(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW.

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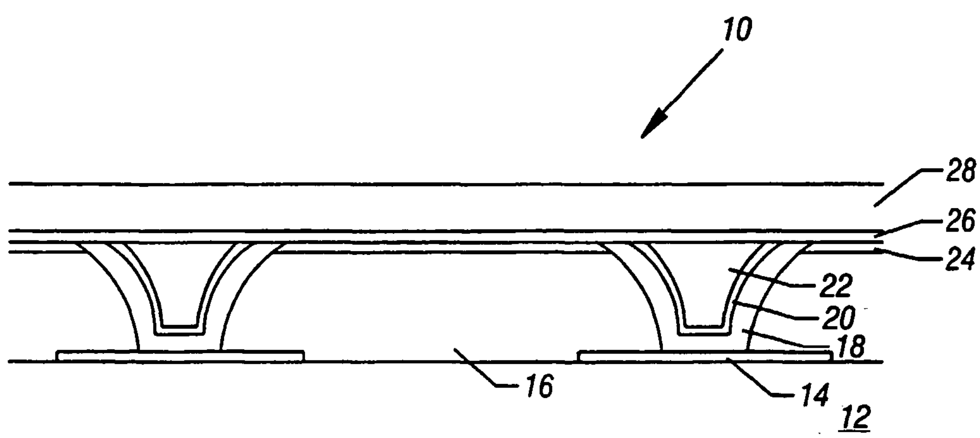
(54) Title: PHASE CHANGE MATERIAL MEMORY DEVICE



(57) Abstract: A phase change material memory cell (10) may be formed with singulated, cup-shaped phase change material (18). The interior of the cup-shaped phase change material (18) may be filled with a thermal insulating material (22). As a result, heat losses upwardly through the phase change material (18) may be reduced and adhesion problems between the phase change material (18) and the rest of the device (10) may likewise be reduced in some embodiments. In addition, a barrier layer (20) may be provided between the upper electrode (28) and the remainder of the device (10) that may reduce species incorporation from the top electrode (28) into the phase change material (18), in some embodiments. Chemical mechanical planarization may be utilized to define the phase change material (18) reducing the effects of phase change material dry etching in some embodiments.

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INTERNATIONAL SEARCH REPORT

International Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L45/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L G11C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 98 58385 A (ENERGY CONVERSION DEVICES INC) 23 December 1998 (1998-12-23) page 16, line 29 -page 27, line 13; figure 1B ---	1-6, 10-15
Y	US 6 031 287 A (HARSHFIELD STEVEN T) 29 February 2000 (2000-02-29) column 12, line 33 -column 13, line 30	1-6, 10-15
X	column 14, line 18 -column 15, line 6; figures 17-23,25	28,29, 31-38
A	column 8, line 64 -column 9, line 66; figures 5-13 ---	7-9, 16-19
Y	US 6 284 643 B1 (REINBERG ALAN R) 4 September 2001 (2001-09-04) column 7, line 55 -column 8, line 38; figure 9 ---	1-6, 10-15
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 February 2004	05/02/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Köpf, C

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 970 336 A (WOLSTENHOLME GRAHAM R ET AL) 19 October 1999 (1999-10-19) column 7, line 50 -column 8, line 67; figures 15-17	20-29, 33,36-39
X	US 6 117 720 A (HARSHFIELD STEVEN T) 12 September 2000 (2000-09-12) column 4, line 22 -column 5, line 13; figures 4-8	20-22, 24,25, 27-30, 33,36-39
X	WO 97 05665 A (ENERGY CONVERSION DEVICES INC) 13 February 1997 (1997-02-13) page 22, line 23 -page 24, line 15; figure 1 page 28, line 7 - line 21	20-27
X	US 5 789 277 A (ZAHORIK RUSSELL C ET AL) 4 August 1998 (1998-08-04) column 8, line 17 -column 10, line 7; figures 7-16	20-27

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 02/26376

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-19

   Method comprising defining an opening, forming a cup-shaped phase change material in the opening, and forming a thermally insulating material in the cup-shaped phase change material; corresponding memory structure

2. Claims: 20-27

   Method comprising defining a phase change material, forming an electrode over the phase change material, and isolating the electrode from the phase change material, particularly by a conductive barrier layer; corresponding memory structure

3. Claims: 28-39

   Method comprising defining an opening in a structure, forming a phase change material into the opening and over the structure, and planarizing the phase change material; corresponding memory structure

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 02/26376

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Form PCT/ISA/210 (patent family annex) (July 1992)